Risk of Fatal Rollover in Utility Vehicles Relative to Static Stability

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Abstract: The risk of fatal rollover of utility vehicles per 100,000 registered vehicles relative to cars during 1982–87 was strongly correlated to the static stability of the vehicles. Distance between the center of the tires divided by twice the height of center of gravity explained 62 per cent of the variation in fatal rollover rates where rollover was the first harmful event. Statistical controls for 20 major risk factors indicated no correlations that would deflate the correlation between stability and rollover. Low stability utility vehicles roll over more often on the road suggesting that the lateral force of turning is often the tipping force. (*Am J Public Health* 1989; 79:300–303.)

Introduction

The sales of utility vehicles, sometimes called multipurpose vehicles, have increased substantially in recent years. In 1986 some 725,000 were sold in the United States compared to 132,000 in 1982.[1] Questions regarding the stability of these vehicles were raised in 1980 when the Jeep CJ-5, the Ford Bronco, and the Chevrolet Blazer were found to have rollover rates per registered vehicle much higher than passenger cars. These utility vehicles also had lower static stability than a sample of cars, as measured by the distance between the center of the tires divided by twice the height of center of gravity, usually expressed as T/2H.[2] T/2H of utility vehicles range from 1 to 1.2 while that of the vast majority of cars is above 1.2 and range as high as 1.6.[2,3]

The principle of static stability can be illustrated easily with a section of 2×4 lumber. Placed on its two inch side, it is easily tipped over by a force from the side, but placed on its four inch side, it tends to slide rather than tip over given the same force. The higher the weight from the ground relative to the width of the bottom decreases the stability. In a moving vehicle, the lateral force generated in a turn provides a potentially tipping force.

Studies of utility vehicles in the early 1980s confirmed the markedly higher rollover rates of utility vehicles relative to cars but did not attempt to correlate the rates with static stability.[4–6] A recent study found that, for the four utility vehicles and 11 cars for which static stability had been published, the fatal rollover rate per registered vehicles during 1981–84 in the US decreased exponentially in relation to static stability. The correlation was almost perfect; static stability explained 96 per cent of the variation among those vehicles. Static stability was not correlated to fatal crash rates where rollover did not occur.[7]

In response to a petition from Congress, the National Highway Traffic Safety Administration (NHTSA) gathered static stability data on a number of vehicles and conducted a study of single-vehicle crashes, mostly nonfatal, in three states. Static stability explained 86 per cent of the variation in rollover per cent.[3]

Since the relative risk of fatal rollover crashes in a number of recently marketed utility vehicles has not been studied, this communication reports an analysis of fatal rollover crashes in relation to static stability of these vehicles, as well as the older ones, during 1982–87 in the US. Other known risk factors were examined as possible confounding factors.

Method

The available data on static stability of utility vehicles that have been measured are presented in Table 1. In some cases, only one vehicle was measured. In the instances of multiple measures, the major intravehicle variation occurs in the vehicles that have the same name for different sized versions, namely Blazers and Broncos. It is possible that some of these vehicles were misidentified at time of measurement or in transmitting the information to NHTSA. In the analysis here, the median value rather than an average is used to minimize the effect of atypical measures or erroneous vehicle identification.

The data on fatal crashes of the utility vehicles in which an occupant of the vehicle died were extracted from the Fatal Accident Reporting System (FARS) data tapes for the calendar years 1982–87.[8] These tapes contain information on virtually every fatal crash in the US with the possible exception of some that occurred in late 1987 and had not been reported when the tape for that year was released. Vehicles were identified by decoding vehicle identification numbers that contain codes specifying makes and models. For comparison, all crashes in which an occupant died in rollovers and nonrollovers were also counted.

Data gathered from state motor vehicle administrations by R.L. Polk Company were used to count registrations by make and model during 1982–84.[9] Since R.L. Polk data do not include vehicles registered in Oklahoma, vehicles that crashed in Oklahoma during the years that registrations were counted from that source were eliminated from the analysis.

TABLE 1—High, Low and Median Stability Ratios (T/2H) Measured by Various Sources

Vehicle	High	Year	Source	Low	Year	Source	Median
1. CJ-5	1.01	79	Snyder	0.99	82	Ford	1.00
2. CJ-7	1.10	81	Unk	1.07	79	Snyder	1.08
3. Pre-78 Bronco	1.10	73	Snyder	1.07	71	Ford	1.08
4. Blazer/Jimmy	1.22	70	TRC	1.16	82	Unk.	1.19
5. Bronco II	1.12	84	Unk	1.01	83	STI	1.07
6. S-Blazer/Jimmy	1.20	85	TRC	1.04	?	Ford	1.07
7. Samurai	1.12	85	STI	1.12	85	STI	1.12
8. Montero	1.07	83	Unk	1.04	85	STI	1.05
9. Wrangler	1.13	87	TRC	1.13	87	TRC	1.13
10. 79+ Bronco	1.12	81	Unk	1.06	83	STI	1.09
11. Cherokee	1.19	83	TRC	1.19	83	TRC	1.19
12. Ramcharger	1.19	79	TRC	1.19	79	TRC	1.19
13. Trouper	1.10	87	TRC	1.10	87	TRC	1.10

DATA SOURCES: Snyder is reference 2; Ford = (Ford Motor Company); STI = (Systems Technology, Inc); TRC = (Transportation Research Center of Ohio); Unk = "unknown source" in the publicly available NHTSA files on rollover petitions.

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The regression coefficient of yearly changes in vehicle registrations by vehicle age was used to estimate scrappage of vehicles as they aged in 1985–87 (per cent change = $-0.28 \times$ vehicle age, $R^2 = 0.31$). For new vehicles, vehicle sales data[1,10] were used to count registrations. The monthly sales were multiplied by the number of months to the end of the study period and the sum of these months was divided by 12 to obtain registered years.

The rate of fatal rollover as "first harmful event," defined as the event causing the initial damage to the vehicle or occupants,[8] was examined for each vehicle with sufficient registrations relative to that of all cars. Log odds of the relative risk was used to establish confidence intervals.

If instability contributes mainly to rollover, there should be little increased risk of nonrollover fatal crash rates of vehicles with low stability ratios. Therefore, the relative risk of nonrollover fatal crashes of the utility vehicles relative to cars was examined as well.

Direct controls for the potential confounding effects of driver's characteristics or driving environment could not be applied since the necessary data on use were unavailable. Maximum potential confounding was estimated for 20 factors by measuring the relation between each factor and stability within the group of fatal rollover crashes. Factors unrelated to stability could not confound the effect of stability on risk. Expressed mathematically:

$$C\,L/H = RL/RH = b(S)$$

where L = low exposure to a risk factor
H = high exposure to a risk factor
C = constant ratio of risk from low to high risk situations
RL = fatal rollovers in low risk-factor situations
RH = fatal rollovers in high risk-factor situations
S = Stability value for a given vehicle
b = the slope of the correlation

This equation says that the ratio of rollovers in low relative to high-risk-factor situations is a function of the ratio of exposures in those situations times the relative risk ratio C. For other risk factors to explain the correlation of static stability to rollover rates, there must be a positive correlation of one or more of the ratios of rollovers by risk factor with static stability. Therefore, if b has a positive value, then the risk factor is a potential confounding factor that inflates the stability effect. A near-zero correlation indicates that the risk factor could not have produced a spurious correlation of stability and rollover rates. A negative correlation implies that the stability effect may be deflated by confounding. The ratio of numbers of rollovers in low relative to high-risk situations were examined for 20 major, known risk factors, including any alcohol and alcohol above the legal limit in the states where 80 per cent or more of fatally injured drivers were tested.

Results

Vehicles that had fewer than 100,000 registered years during the study period—the Montero, Trouper, and Wrangler—were eliminated from the analysis. Table 2 presents the analysis of the relative risk of fatal rollover as first harmful event in relation to the all-car rate, 1.3 per 100,000 registered vehicles. The Jeep CJ-5 was 19.7 times more likely to experience a fatal rollover per registered vehicle than a car. The Jeep CJ-7, the pre-78 Ford Bronco, and the Ford BroncoII were clustered in the range of 10 to 12 times the fatal rollover rate of cars. Another cluster with a relative risk three to six times that of cars included the Dodge Ramcharger, the 1982–87 Ford Bronco, the General Motors large and small Blazer/Jimmys and the Suzuki Samurai. The lowest relative risk was 1.3 for the Jeep Cherokee and the lower confidence limit for that vehicle was the only one within the range of all cars.

The relation of the first-harmful-event rollover rate to the stability ratio, T/2H, displayed in Figure 1, is striking. The higher the stability the lower the fatal rollover rate. In a linear model, 62 per cent of the variation among vehicles was accounted for by the stability ratio. The regression coefficient of -86 (95% confidence interval = -39 to -132) suggests that increasing the stability ratio by one-tenth decreases the annual fatal rollover rate by an average of about 9 per 100,000 registered vehicles, within the range of stability ratios of the vehicles in the study.

Since vehicles sometimes roll over subsequent to other "first harmful events," the correlation of stability ratios with rate of rollover as "most harmful event" was also examined. The pattern was similar to that in Figure 1 but the rates were higher.* The regression coefficient of -143 (95% CI = -64 to -222, $R^2 = 0.61$) suggests that an increase in the stability ratio of one-tenth would decrease the annual most-harmful-event rollover rate in which an occupant dies by an average 14 per 100,000 vehicles, again within the range of stability ratios of these vehicles.

The risk ratios for utility vehicle occupants relative to car occupants of fatal crashes without rollover are displayed in Table 3. Eight of the 10 vehicles had risk ratios less than one relative to cars, two with upper bound less than one. Only the Jeep CJs had confidence intervals above and outside the range of the all-car rate and their relative risk ratios were less than two.

The relation between stability and driver or environmental characteristics is shown in Table 4. None of the 20 risk factors was substantially positively correlated to T/2H. The on-road/left-road correlation was negative, indicating that lower stability vehicles more often rolled over on the road rather than after leaving the road, as plotted in Figure 2.

The other environmental risk factors were unrelated systematically to vehicle stability. No driver factor was correlated systematically to vehicle stability, including age, gender, presence of alcohol or illegal alcohol, invalid licenses, prior crashes, prior suspensions or convictions for driving while intoxicated, speeding, or other offenses.

*Data available on request to the author.

TABLE 2—Relative Risks of Fatal Rollover Crashes

Vehicle Model	Model Years	Fatal Rollovers	100,000 Year Registered	Relative Risk	95% CI
All passenger cars	all	9813	7790.6	1.0	
Jeep CJ-5	67–83	354	14.3	19.7	17.7–21.9
Jeep CJ-7	76–86	216	13.8	12.4	10.8–14.2
Ford Bronco	74–77	84	5.9	11.3	9.1–14.0
Ford Bronco II	83–87	141	11.0	10.2	8.6–12.1
Suzuki Samurai	86–87	9	1.2	6.1	3.2–11.8
Ford Bronco	82–87	51	7.1	5.7	4.3– 7.5
GM Blazer/Jimmy	69–87	222	32.8	5.4	4.7– 6.1
GM S-Blazer/ S-Jimmy	82–87	89	22.1	3.2	2.6– 3.9
Dodge Ramcharger	82–87	15	3.8	3.1	1.9– 5.2
Jeep Cherokee	75–83	11	6.9	1.3	0.7– 2.3

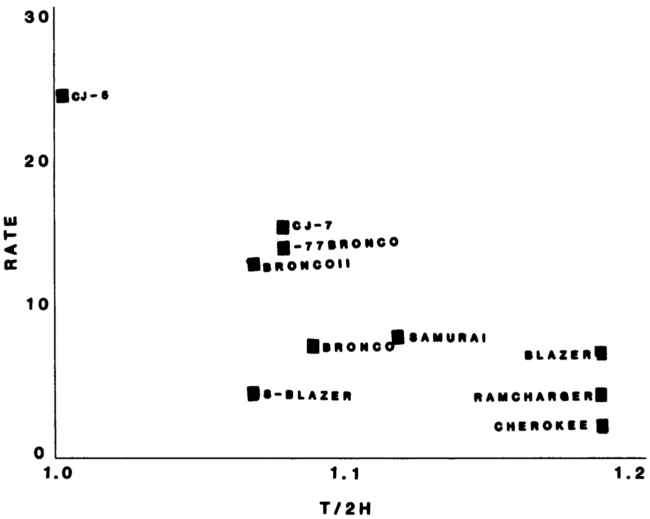

FIGURE 1—Fatal Rollover Crashes per 100,000 Registered Vehicles

Discussion

These and previously published data leave little doubt that vehicle stability is the primary factor contributing to the higher fatal rollover crashes in utility vehicles than cars. The result is consistent with well-known principles of physics. The nonrollover fatal crash rate of utility vehicles, which is caused by factors other than stability, is similar to that of cars. None of the powerful predictors of fatal crashes generally—rural roads,[11] lack of light,[12] prior driving record,[13] alcohol,[14] age and gender[15]—were related to stability ratios in such a way as to be confounding factors.

The only risk factor related to stability is the on-road/off-road factor. The fact that the less stable vehicles more often roll over on the road is consistent with the hypothesis that many more of them roll over because of the lateral force of turning alone, or perhaps even occasionally by very strong side winds, rather than going over embankments or ramping, which is much more likely to happen off the road rather than on it.

The possibility that some combination of risk factors contributes to the correlation of stability and rollover is extremely remote. The factors most strongly predictive of fatal crashes generally, such as age and gender, are known to be independently correlated to the risk of a fatal crash.[12] While all of the risk factors examined do not occur independently of one another, the fatal rollover crashes are distributed among the categories of the factors in such a way that high enough concentration in some important combination, which is also in turn strongly combined with low stability vehicles, is not possible given the lack of correlation of stability with the factors considered separately.

Despite widespread publicity in 1980 regarding the rollover propensity of the Jeep CJs, several manufacturers have subsequently introduced new vehicles with low stability. The lack of a perfect correlation of rollover rates with static stability suggests that some manufacturers of later model vehicles may have partially offset the effect with better than average suspension systems or other vehicle characteristics moderating the tendency of lower stability vehicles to

TABLE 3—Relative Risks of Fatal Nonrollover Crashes to Occupants of Utility Vehicles Relative to the All-Car Rate

Vehicle Model	Model Years	Fatal Nonrollovers	Relative Risk	95% CI
All passengers cars	all	100,886	1.0	
Jeep CJ-5	67–83	320	1.7	1.5–1.9
Jeep CJ-7	76–86	244	1.4	1.2–1.6
Ford Bronco	74–77	64	0.8	0.7–1.1
Ford Bronco II	83–87	96	0.7	0.6–0.8
Suzuki Samurai	86–87	14	0.9	0.6–1.6
Ford Bronco	82–87	77	0.8	0.7–1.0
GM Blazer/Jimmy	69–87	335	0.8	0.7–0.9
GM S-Blazer/ S-Jimmy	82–87	245	0.9	0.8–1.0
Dodge Ramcharger	82–87	35	0.7	0.5–1.0
Jeep Cherokee	75–83	77	0.8	0.7–1.0

TABLE 4—Regression Analysis of Ratio of Number of Rollovers in Low- and High-Risk Situations by Static Stability

Environment	T/2H Coefficient	95% CI Lower	95% CI Upper	% Variance Explained
Urban/Rural	−0.67	−1.89	0.56	14
Interstate/Other	1.91	−0.40	4.23	27
On Road/Off Road	−3.96	−7.27	−0.64	44
3+ lanes/2 lane	0.05	−0.30	0.40	1
Speed limit <55/55+	−1.39	−2.91	0.12	32
Straight/Curve	3.40	−1.73	8.54	19
Level/Grade	−1.46	−8.47	5.55	2
Concrete/Blacktop	0.10	−0.66	0.86	1
Dry/Wet	−14.68	−75.47	46.11	3
Daylight/Other	2.05	−0.89	4.99	21
Driver				
Valid License/Other	0.56	−0.36	1.47	17
No Prior Crash/1+	−8.52	−24.31	7.28	14
No Prior Suspension/1+	−29.49	−85.07	26.10	15
No Prior DWI/1+	−27.89	−71.07	15.29	21
No Prior Speeding/1+	8.78	−4.22	21.79	18
No Other Conviction/1+	6.30	−16.53	29.13	4
No Blood Alcohol/0.01+	−0.21	−3.49	3.07	3
No Illegal BAC/0.10+	1.23	−4.93	7.39	3
<25 years old/25+	6.41	−3.32	16.15	17
Women/Men	−0.27	−1.76	1.22	2

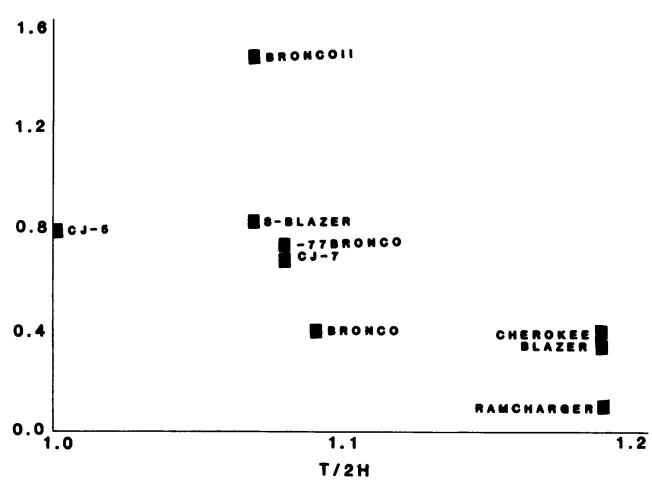

FIGURE 2—Ratio of Rollovers on the Road to Rollovers After Leaving the Road (Excludes the Samurai for which there were less than 10 cases)

tip over in turns. Nevertheless, the static stability is a strong predictor that could be used to set standards for vehicles.

The National Highway Traffic Safety Administration has denied petitions to address the problem.[16,17] The agency's main justification for its inaction was that static stability is a continuously distributed variable and that to choose a required point would be arbitrary. It also said that it is prohibited by law from banning a class of vehicles which such a standard would do. If standards could not be set on continuously distributed factors, however, there would be no standards for blood alcohol concentration and head injury criteria. Since a standard for static stability could be met by simply widening the distance between the center of the tires and/or lowering the center of gravity, such a standard would not ban a class of vehicles. Furthermore, one utility vehicle with stability in the range of that of passenger cars had a rollover rate similar to passenger cars.

Another issue is whether the vehicles now in use should be recalled and modified to reduce rollover risk. Smaller diameter tires would reduce the height of the center of gravity on the high-risk vehicles. It may also be possible to weld some weight along the undersides of the vehicles to make them more stable. Given the risk and the fact that each cohort of these vehicles will be in use an average of more than 10 years, a testing program seems indicated to evaluate the effect of such modifications on stability.

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4th National Environmental Health Conference, June 20–23

The Center for Environmental Health and Injury Control of the Centers for Disease Control; the Agency for Toxic Substances and Disease Registry; and the Association of State and Territorial Health Officials have announced the Fourth National Environmental Health Conference will be held June 20–23, 1989, in San Antonio, Texas. The primary audience is federal, state, and local health and environmental officials and physicians and the environmental community.

The theme of the 1989 conference is "Environmental Issues: Today's Challenge for the Future." The objectives are to: address the environmental insults that have the greatest importance to public health; review topical scientific findings; and discuss prevention strategies. Plenary sessions will be on radon; medical, municipal, and hazardous waste; air pollution; lead in the environment; and dioxin. Twenty workshops will be held on topics of interest to states, academic institutions, and federal agencies including health assessments at NPL (national priorities list) and RCRA (Resource Conservation and Recovery Act) sites, emergency responding, radiation, birth defects, risk communication, indoor air pollution, and respiratory disease.

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